Anisotropic Diffusion Despeckling for High Resolution SAR Images

Chen Xi[1] Wang Chao[1] Zhang Hong[2] Tang Yixian[1]
[1]National Key Laboratory of Remote Sensing Science, Inst. of Remote Sensing Appli. ,CAS , Beijing, 100101, China; [2]College of Geography & Remote Sensing Science, Beijing Normal University, Beijing, 100875, China
Tel:(86)010-64854300-8033 E-mail: chenxi@lab.irsa.ac.cn

KEY WORDS： SAR, Speckle, Anisotropic Diffusion, High Resolution

ABSTRACT： The main purpose of this work is to perform a new denoising method based on a nonlinear anisotropic diffusion for the reducing of the multiplicative speckle in high resolution Synthetic Aperture Radar (SAR) images. In order to be applicable to the sampled data and reduce computing complexity, an efficient discretization scheme, e.g. additive operator splitting(AOS) scheme is chosen here for the proposed approach. Examples are given comparing the new filter to established speckle noise reduction methods on an ERS-2 SAR image. Experimental results show that this method not only can effectively reduce speckle, while preserving important discontinuities present in the input data, but also obtain a better performance than the traditional local statistical filter.

1 INTRODUCTION

The basic goal of SAR images denoising is that preserving the image detail characteristics like edges and textures, while suppressing the speckle of uniform area in the image. The most classical approach can be implemented by multi-look despeckling in the imaging processing. But this increase in radiometric resolution is gained at the expense of spatial resolution. As for the multiplicative characteristic of the speckle, many spatial domain filtering algorithm[1] have been developed, and gradually become the mainstream technique of the SAR image despeckling, the typical approaches include the adaptive local statistical filter (like lee filter, kuan filter, etc) and geometric filter etc, the key of this kind of approach consist in how to achieve effective despeckling according to the statistical property of the sliding estimated window and choose the appropriate window size to gain the biggest homogeneous region. In addition, filtering technique based on iteration and wavelet approach [8] and EMD approach [2] proposed by Han et al. both obtain a good performance in reducing speckle.

In recent years, the image processing approach based on nonlinear diffusion have already been applied in the field of image enhancement, image segmentation and scale space analysis etc [3][4][5][6], its trait is reducing the noise and sharpening edges at the same time. In order that the continuous anisotropic diffusion equation is applied in the discrete image data, the nonlinear diffusion filtering algorithm based on additive operator splitting(AOS) scheme is proposed, and then compare its performance with the traditional SAR speckle filter, the experiment results show that，based on several evaluation measure, this approach not only achieve good balance between reducing noise and preserving edges, but also obtain a better performance than the traditional local statistical filter.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **NOV 2004**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Anisotropic Diffusion Despeckling for High Resolution SAR Images**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **AFOSR/Asian Office of Aerospace R & D Unit 45002 APO AP 96337-5002**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
Proceedings of the 25th Asian Conference on Remote Sensing, Held in Chiang Mai, Thailand on 22-26 November 2004. Copyrighted; Government Purpose Rights License. Published by Geo-Informatics and Space Technology Development Agency.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

2 NONLINEAR DIFFUSION FILTERING

2.1 The Physical Background of Diffusion

Firstly, giving the heat diffusion equation

$$\partial_t u = div(D \cdot \nabla u) \tag{1}$$

Where, u is concentration, div is the divergence operator , ∇ is the gradient operator , D is diffusion tensor and t is time. This equation appears in many physical transport processes. In image processing, the concentration can be considered as the gray value at some position. If D itself depends on the evolving image u, the resulting equation describes a nonlinear diffusion filter.

Nonlinear diffusion was first proposed by Perona and Malik in 1990[7]，and built the following isotropic diffusion model：

$$\partial_t u = div(g(|\nabla u|) \cdot \nabla u) \tag{2}$$

But Perona-Malik model still have some fault. Thus, Catte et al. proposed that, by substituting the gradient $|\nabla u|$ with its estimate $|\nabla G_\sigma * u|$ where G_σ can be any smoothing kernel, nonlinear diffusion filter can be more robust for noise. While as for the problem of the unfiltered edge noise，it have to turn to the anisotropic filters where the flux $j = -D \cdot \nabla u$ is not generally parallel to the image gradient.

2.2 Anisotropic Diffusion Model

Generally, the presence of the noise near the edges result in the fluctuation of the image gradient, consequently cause the fluctuation of the gradient intensity and direction. Nonlinear isotropic diffusion filter includes a scalar diffusion tensor $D = g(|\nabla u_\sigma|)$， so the flux always parallel to the image gradient ∇u , noise near the edges can not be smoothed, however rotate it, then diffusion filter can filtering noise near the edges, thus the diffusion tensor which controls the diffusion process should be not a scalar but a matrix $D = \begin{pmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{pmatrix}$, and nonlinear anisotropic diffusion equation is introduced：

$$\partial_t u = div(D(\nabla u_\sigma) \cdot \nabla u) \tag{3}$$

Here，an edge-enhancing diffusion model is adopted.

$$\varphi_1 = g(|\nabla u_\sigma|)$$

$$\varphi_2 = 0.2 \tag{4}$$

where φ_1 controls the diffusion in the gradient direction, φ_2 controls the smoothing in the coherence direction. The value of φ_2 lies in the interval [0, 1].

2.3 Diffusivity Function *g*

Diffusivity function g is a non-increasing function, its value lies in the interval [0,1].The function g*(s)* plays a role of a 'fuzzy detector' of the presence of an edge at a particular position.

Edge-enhancing diffusion can adopt the diffusivity function proposed by Weickert：

$$g(s) = 1 - \exp\left(\frac{C}{(s/\lambda)^m} \right) \tag{5}$$

with C= -2.33667 and m=4 here. This diffusivity and the corresponding flux function is drawn in Figure1.

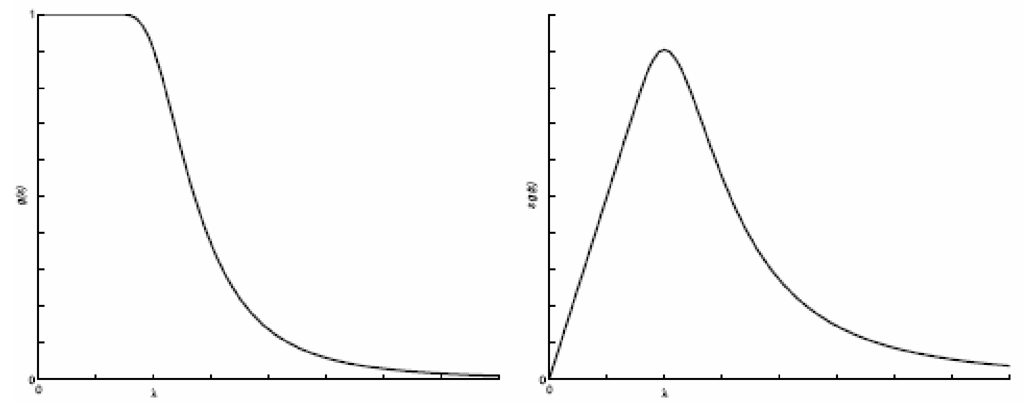

Figure 1. The Weickert diffusivity(left) and the corresponding flux function $s \cdot g(s)$ (right)

2.4 Discretization Scheme

In order that the continuous anisotropic diffusion equation is applied in the discrete image data, an effective semi-implicit discretization scheme, e.g. the AOS scheme, can be employed.

$$u^{k+1} = \frac{1}{m} \sum_{l=1}^{m} (I - m\tau A_l(u^k))^{-1} u^k \tag{6}$$

with l is the direction index, l=1,…,m。

The AOS scheme will separate the 2D diffusion into several one-dimensional diffusion process along chosen directions, it is absolutely stable for any discretization time step, and contain simple and effective calculation in an iterative process.

3 EXPERIMENT RESULTS AND ANALYSIS

3.1 Evaluation Measures

For objectively evaluating the effectivity of the nonlinear diffusion filter, several measure is chosen to evaluate the despeckling performance:(1)the capacity of despeckling in uniform areas;(2)the capacity of preserving edges information;(3)the capacity of keeping the average value of the image.

So the parameter ENL is employed to measure the smoothing performance of the speckle filter:

$$ENL = \mu_x^2 / \sigma_x^2 \tag{7}$$

where μ and σ represent the mean and the variance of the filtered image respectively. While the parameter EPI is employed to measure the capacity of preserving the edge of the filtering algorithm:

$$EPI = \sum | p_s - p_{sn} | / \sum | p_o - p_{on} | \tag{8}$$

with p_s is the pixel value of the filtered image, p_{sn} is the neighborhood pixel value of p_s, p_o is the pixel value of the original image, p_{on} is the neighborhood pixel value of p_o.

The PM represent the capacity of keeping the mean value of the image, it is defined as the ratio of the mean value of the original image and the filtered image.

3.2 Experiment Analysis

An ERS-2 image is selected for the despeckling experiments. The experiment test and contrast between the proposed nonlinear diffusion approach and several common adaptive local statistical filter, like frost, lee, kuan etc, is done. Figure2-Figure7 show the filtering results. The parameter used in this diffusion filter is shown as follow: $\sigma = 1.0$, $\tau = 1$, T=2. Table1 give the analysis result of the experiment.

Firstly in terms of vision effect, the performance of the nonlinear anisotropic diffusion filter in SAR image despeckling is good, it not only effectively reduce noise, but also preserve the edges information of the image. Seeing from its filtered image, for the river and the homogenous area lying the river side, a good performance is shown, and the texture of the mountains appear a better interpretation performance by eyes than the original image.

From table 1, it is clear that for any evaluation measure, the despeckling algorithm based on nonlinear diffusion is optimal，others algorithm also can better keep the mean value of the image, and reduce the variance of the image, but obtaining a good performance both in smoothing noise and preserving edge appear difficult. However nonlinear diffusion filtering algorithm not only gain a good balance between reducing noise and preserving edges, but also obtain a better performance than the traditional local statistical filter. Furthermore, because of the physical essence of just transporting mass of the diffusion, its capacity of keeping the mean value of the image is so strong, the mean value of the filtered image compared with one of the original image nearly constant according to table 1, which is of important meaning for the further image interpretation. Thus, considering the evaluation measure all together, the nonlinear diffusion filter can effectively reduce the speckle in the SAR images, while preserve the important detail information.

Table 1 The contrast of several despeckling algorithm

	Mean	Variance	PM	ENL	EPI
Original image	39.757342	51.38114	1.000000	0.598725	1.000000
Kuan Filter	39.910042	30.49218	1.003841	1.713119	0.284019
En-Lee Filter	39.567267	31.527652	0.995219	1.575030	0.313529
En-Frost Filter	39.807742	30.733126	1.001268	1.677728	0.290327
Gamma MAP Filter	38.095198	30.769653	0.958193	1.532835	0.296259
AOS ND Filter	39.757960	30.298864	1.000016	1.722851	0.330310


Figure 2 Original noisy image

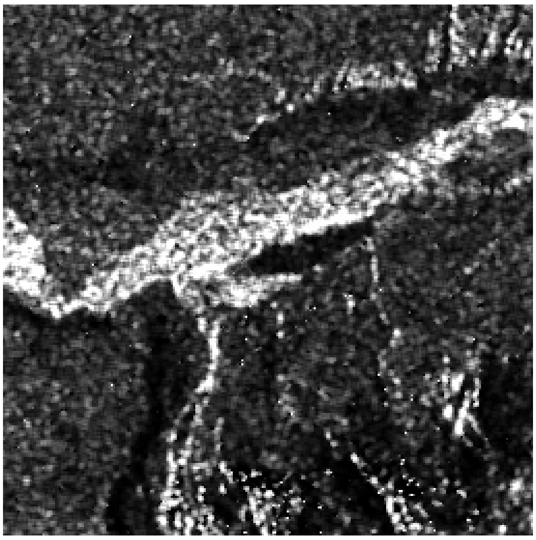
Figure 3 Result of En-frost filter

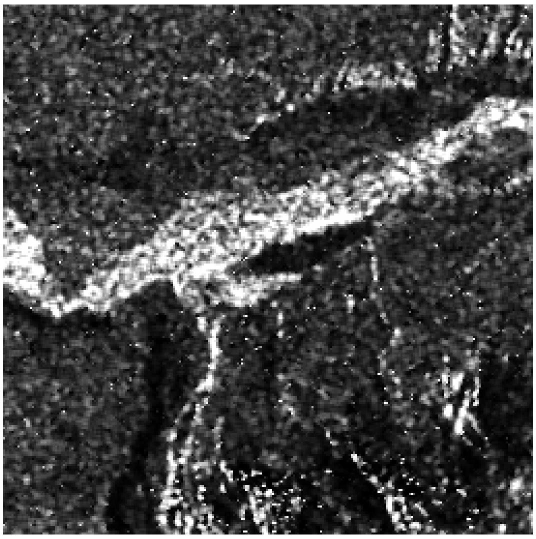
Figure 4 Result of En-lee filter

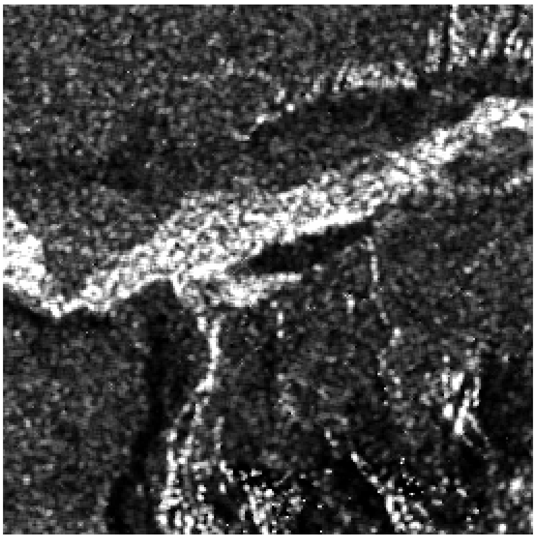
Figure 5 Result of Kuan filter

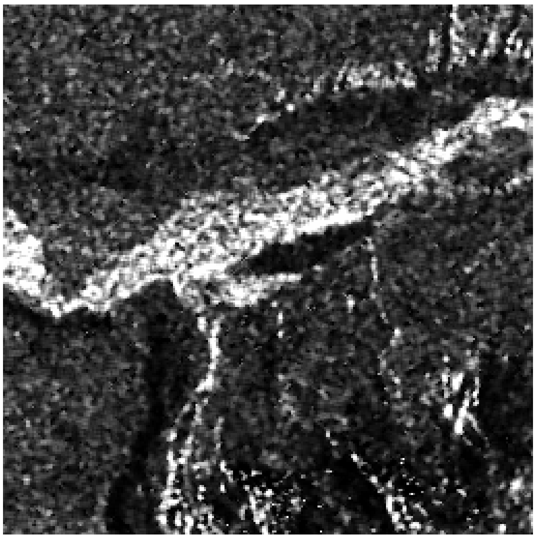

Figure 6 Result of Gamma filter

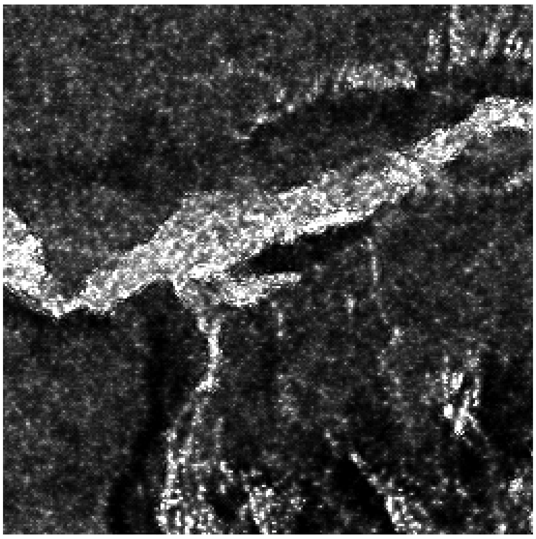

Figure 7 Result of our method

4 CONCLUSION

Speckle is the intrinsic characteristics of the SAR images and significantly effects the remote sensing application of the SAR images. The present main problem of the traditional adaptive filter based on local statistical characteristics lies in how to gain a better balance between preserving texture detail and despeckling. So, according to the trait of nonlinear diffusion filter, the attempt to introduce in SAR image despeckling is done, and by experiment test and contrast, the proposed approach achieve a better striking experiment performance than the traditional adaptive local statistical characteristics filter.

REFERENCES

[1] GUAN Bao, SUN Hong.Iterated filtering method of SAR image[J].Chinese Journal of Radio Science, 2003, 18(1): 12-17.

[2] HAN Chun-ming, GUO Hua-dong, WANG Chang-lin. Speckle Suppression Using the Empirical Mode Decomposition[J]. Journal of Remote Sensing, 2002, 6(4): 266-271.

[3] Joachim Weickert. A Review of Nonlinear Diffusion Filtering[J]. Scale-Space Theory in Computer Vision，1997，1252：3-28.

[4] LU Yisong, CHEN Yazhu, Guo Yuhong. A medical Image Nonlinear Filtering Method Based on Anisotropic Diffusion[J].Beijing Biomedical Engineering, 2003, 22(2):81-84.

[5] Scott T.Acton.Locally Monotonic Diffusion. IEEE Transaction on Signal Processing，2000，48(5).

[6] Pavel Mrazek. Nonlinear Diffusion for Image Filtering and Monotonicity Enhancement[D]. Prague：Czech Technical University，2001.

[7] P Perona，J Malik. Scale-space and Edge Detection using Anisotropic Diffusion [J]. IEEE Transactions on Pattern Analysis and Machine Intelligence，1990，12(7)：629-639.

[8] TANG Yuan-jiu, HUANG ka-ma, ZHANG Min, HE Ming-shou.The application of a filtering method based on wavelet transform in biomedical electromagnetic imaging[J].Chinese Jouranl of Radio Science, 2000, 15(4):402-405.